Wood and Other Renewable Resources (Subject Editor: Jörg Schweinle)

Environmental Effects from a Recycling Rate Increase of Cardboard of Aseptic Packaging System for Milk Using Life Cycle Approach*

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DOI: http://dx.doi.org/10.1065/lca2007.06.340

Please cite this paper as: Mourad AL, Garcia EES, Vilela GB, von Zuben F (2008): Environmental Effects from a Recycling Rate Increase of Cardboard of Aseptic Packaging System for Milk Using Life Cycle Approach. Int J LCA 13 (2) 140–146

Abstract

Goal, Scope and Background. Despite the well-known advantages of recycling materials to reduce solid waste or save natural resources, the recycling stage is an additional process within the life cycle that has its own energy and input requirements, as well as specific emissions. The objective of the present paper is to analyze the life cycle inventory associated with the increase in recycling rate (from 2% up to 22% at present) of the cardboard contained in the aseptic packaging for long-life milk. The main aspects of the manufacturing of the Tetra Pak aseptic package, including the filling of the product, the distribution of the conditioned product, up to the final disposal and recycling rates, were considered.

Materials and Methods. This study was conducted in accordance with the general directives of the ISO 14040 series. The packaging material system was assessed using 1000 liters of milk as a functional unit, in a packaging system containing 12 units of 1 L cartons each, placed on a corrugated paperboard tray wrapped in polyethylene shrink film and arranged onto one-way wooden pallets. Brazilian inventories for energy, carton, corrugated paperboard and aluminum, based on site-collected data were employed. The final disposal of used packages was modeled using the Average Brazilian Municipal Solid Waste Management data collected for the purpose of the census of the year 2000.

Results. Comparison of the total energy consumption throughout the whole life cycle of two recycling scenarios (i.e. different recycling rates) analyzed shows that the higher recycling rate led to a 6% reduction of the total energy requirement for the long-life milk package material system. The most significant reductions in the consumption of natural resources were: 8% water, 11% wood and 10% land use savings. Greenhouse gases were the main reduced air emissions and contributed with a reduction of 9.7% in GWP. Most water emissions were reduced: 10% COD, 9% BOD and 6% TSS. A unique drawback directly caused by the increase of the recycling rate was an increase of 14.4 g in TDS emissions (57%).

Discussion. The reduction in energy requirements are related and limited to the proportionality among the different materials that make up the packaging system. Most emission reductions result from the replacement of virgin materials with recycled materials in the packaging system. Although the average balance of water emissions is positive, the need to improve wastewater treatment processes in the paper recycling plants to reduce TDS is highlighted as a key issue.

Conclusions. It may be concluded that the increase in the recycling rate brings about a series of benefits in terms of reduction of energy and natural resource consumption, air pollutants and most water emissions. In this case, the increase of the recycling rate improved the overall environmental performance of the aseptic Tetra Pak system for milk.

Recommendations and Perspectives. The authors are currently analyzing alternative recycling scenarios that will enable one to evaluate maximum reduction in GWP. Further studies could include the agriculture stages, livestock and consumer phase to broaden the environmental evaluation.

Keywords: Emissions; LCIA; recycling rate; Tetra Brik aseptic carton

Introduction

LCA constitutes an important instrument to evaluate the environmental effects brought about by changes in processing technologies, efficiency improvements, substitution of raw materials, recycling, etc. When the inventory generated is looked at from a historical perspective, the environmental improvements can be measured and compared to past data. Communication is easier among the stakeholders along the entire product lyfe cycle chain. The overview of the product process chain allows us to assess the benefits and the drawbacks of different alternatives. The recycling process is an additional or complementary process that has its own energy and input requirements, as well as process-specific emissions. Collection and transport of post-consumption residues up to the recycling plant usually produces emissions into the air. Thus, from an environmental point of view, it is necessary to balance all of the processes in order to evaluate the advantages of the recycling processes. Finnveden and Ekwall (1998) evaluated the results of 11 studies (conducted in Sweden, Western Europe, Denmark and Germany) comparing recycling versus paper incineration and found a clear environmental advantage for recycling. Some studies have been reported involving LCA of milk packagings. A detailed LCA study for the dairy sector including the production of milk at farm level and milk processing at the dairy plant was conducted by Hospido (2003) using different databases.

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The main environmental impacts found were eutrophication, acidification and global warming potential. Eutrophication and acidification were generated at the farms and dairies, whereas the impacts on GWP were mainly associated with the Tetra Pak package.

Lundholm and Sundström (1985) carried out a study aiming to elucidate the environmental effects of the Tetra Pak aseptic package designed for juice, non-carbonated fruit beverages, wine and other non-dairy liquid food products. For reference, environmental effects have also been assessed for two other packaging systems, one being a disposable glass bottle and the other a refillable glass bottle with an estimated life of 10–20 trips. Due to the similarity of this study, some of their findings are compared with those of this paper.

1 Objective

Brazil is a very large country, with specific characteristics in terms of the renewable energy matrix, long transport distances and a specific national waste management profile. For that reason, the purpose of this work is to analyze – within the limits of the average Brazilian situation – the changes in the consumption of natural resources and emissions into the atmosphere and water bodies and the generation of solids associated with the increase of the recycling rate (from 2% up to 22% at present) of the cardboard present in the aseptic packaging for long-life milk.

2 Methods

This study has been conducted in accordance with the recommendations of International Standards ISO 14040 – Environment management – Life cycle assessment – Principles and framework (1997) and 14041 – Environment management – Life cycle assessment – Goal and scope definition and inventory analysis.

2.1 System evaluated and the functional unit

The functional unit considers the complete packaging system: 1,000 liters of milk, distributed in corrugated paperboard trays with 12 x 1 L units, wrapped with polyethylene shrink film, arranged on one-way wooden pallets.

The aseptic packaging material is composed of a laminate of paper, polyethylene and aluminum foil. Each layer of the laminate has specific functions: the paper delivers stiffness to the packaging; polyethylene is a liquid barrier and the aluminum foil blocks out light and oxygen, extending the shelf life of the milk for 3 months, without refrigeration or preservatives.

The main aspects of the manufacturing of the Tetra Pak aseptic package, including the filling of the product, the distribution of the conditioned product up to final disposal and recycling rates, were considered.

2.2 Boundaries of the study

The inventories concerning the manufacturing of the packaging materials consider the extraction of natural resources: polyethylene from crude oil or equivalent; cellulose from trees (silviculture) and aluminum from bauxite. After extraction, the manufacturing of the raw materials, their processing, the manufacturing of the packaging materials, the

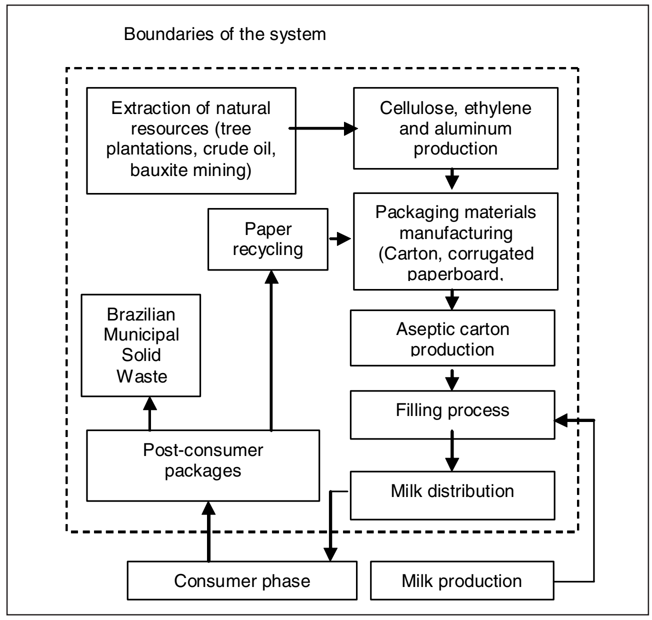

Fig. 1: Boundaries of the evaluated system

filling process, their disposal, final destination and the recycling rate after consumption, were considered. The main aspects related to filling, sealing and sterilization of the packaging were considered. Shipping of the processed product to retail outlets and the transport of post-consumption materials (used packages) for recycling or final disposal were also included, as outlined in **Fig. 1**.

Since life cycle studies have been conducted in Brazil only since 1998, only a limited number of industrial processes have been extensively studied to date. Due to the specific characteristics of the country, CETEA decided to incorporate only national Brazilian data into their projects. For that reason, the following aspects were excluded when the boundaries of this study were defined: a) the life cycle of milk (agriculture, livestock fodder production, consumption and domestic disposal); b) the production of the inputs used in the manufacturing of the packaging materials, such as caustic soda, sodium sulphate, aluminum sulphate, kaolin, starch, etc.; c) the treatment of milk prior to being packaged, sterilization, pasteurization or other heat treatment and d) the emissions of truck engines burning diesel fuel throughout the distribution chain of the finished product (gas stations) and the final delivery to retail outlets by road.

2.3 The manufacturing of the asepticTetra Pak laminate

The production of the asepticTetra Pak laminate used to manufacture containers intended to hold liquid foods consists of the printing of the cardboard, followed by laminating with aluminum foil with extrusion of LDPE and the application of the internal layers of LDPE, also by extrusion. The transport steps considered for the manufacturing of the cardboard take into account the distance between the suppliers of the raw materials (cardboard, polyethylene, aluminum and ink) and the plant located in the city of Monte Mor, SP. Transport with heavy and medium-sized trucks were considered. In those cases where the truck returned empty to its point of origin, the distances were doubled.

2.4 Filling of the product

Roll-fed packaging material is sterilized and shaped into a tube on the TBA machines. The tube is filled with the product and the packages are shaped and sealed below the surface of the liquid

The consumption of electric energy, water vapor and water considered were based on the characteristics of the TBA machines available on the industrial market in Brazil and are identical to the data used in the study from the year 2000. The data relative to the treatment and sterilization of the milk were excluded from this study. The factors associated with the sterilization of the packaging material, the shaping of the Tetra Pak aseptic package and the filling of the milk were quantified. Process losses inherent to the production of the Tetra Pak aseptic package were estimated at 0.5% of the corrugated paperboard and carton structure and it was considered that these residues were further dealt with according to the Brazilian average solid waste management profile.

2.5 The transport steps

The transport distances involved in the production of raw and recycled materials were calculated based on the average distance between each supplier and the plant studied. The emissions generated during transport were included in the inventory of each packaging material. The most significant transport distances in the final inventory were: 900 and 2,070 km between the manufacturing sites of the carton and aluminum used and the aseptic carton production plant; 840 and 100 km between the aseptic carton and corrugated paperboard production sites and the milk filling stations; and 900 km for the transportation of post-consumption packages to the paper recycling plant. The average distribution radius for packaged milk was estimated at 200 km, since there are long-life milk producers in practically all regions in the country.

Heavy trucks (> 18 metric tons) were used in most of the transportation stages, except for the shipping of post-consumption packagings up to the paper recycling plants, which is normally accomplished using medium-sized vehicles (6–18 metric tons). European emission factors (Faiz 1999) were adjusted to the average diesel consumption rates of the Brazilian truck fleet due to the unavailability of local data and the similarity of the fuel consumption levels in EuropeSelective collection is carried out by street collectors who live at the Bottom of the Pyramid (BoP) and try to make a living out of collecting saleable material from household garbage. There are approximately 400,000 street collectors in Brazil.

2.6 Recycling rates

Tetra Pak, in close collaboration with all the stakeholders of the whole productive chain, raised the recycling rate of its post-consumption long-life milk packagings from 2% (2000) to 22% (2004) by encouraging the implementation of selective collection programs. One of the main objectives of this study has been to assess the effect of this increase in recycling rates. These rates refer to the carton structure and the recovery of only the cardboard. As cardboard represents 75% of the total aseptic package mass, the actual recycled cardboard rates considered for the purpose of this study were on the order of 1.5 and 16.5%. The cellulose material from the post-consumption packages gives high quality fibers, most of which (around 90% of the total fiber content) are recovered by a corrugated paperboard company and re-used in the production of new distribution boxes. No environmental burden was assigned for waste paper as input material, in accordance with the ecoinvent (Hischier 2005).

The Brazilian Association of Corrugated Paperboard (ABPO) reported an average recycling rate of 77.3% for 2004. For shrink film residues, an average recycling rate of 20% was considered. The recycling of aluminum and polyethylene has not been taken into account in this evaluation.

2.7 Brazilian database representativeness

Energy. In Brazil, electric energy for public utility services is produced by an interconnected system of electric plants, mostly hydro-electric (93.5%). A large part of the paper manufacturers, however, are almost self-sufficient in terms of electric power and generate electric energy from the burning of black liquor and plant biomass. Black liquor is a mixture of cooking chemicals and dissolved wood material remaining after soda or sulphate pulp cooking. Most of the energy used in oil refineries is generated from their own by-products, therefore, from fossil fuels. The main aspects (consumption and emission) of the extraction and production processes of fossil fuels (pre-combustion), such as diesel oil, fuel oil, coal, natural gas and liquefied petroleum gas, have been included within the boundaries of the study. In Brazil, goods are predominantly transported by road. The emissions generated by trucks burning diesel fuel have been considered for the transport of all the main inputs used in the manufacture of packaging materials, from the extraction of raw materials, manufacturing of intermediary products up to the obtainment of the final packaging material.

The data concerning the generation and distribution of Brazilian electric energy are based on the data collected between 1997 and 1998, and updated in 2000 (Coltro 2003).

Packing materials. The data concerning the production of cardboard were provided by the main supplier of cardboard used in the manufacturing of the Tetra Pak aseptic carton (Mourad 2000a).

The LCA inventories of corrugated paperboard boxes incorporate the data contained in the Brazilian average inventory of the companies involved in the production of this packaging material from 1997 to 1998: participations over 75% (paperboard liners), 75% (medium papers) and 50% (corrugated paperboards), considering the market share of each collaborating company, representing the data collected from 18 plants (Mourad 2000b).

The data concerning the production of ethylene (catalytic cracking of naphtha) from crude oil refining were estimated based on Brazilian public sector data and the study published by BOUSTED. The manufacturing of low density polyethylene (polymerization) from ethylene was quantified from the data obtained from the two resin suppliers of Tetra Pak, weighted by the rate of supply in 1997/1998. The manufacturing data of the aseptic carton structure refer to a Tetra Pak plant in Brazil, assessed between 1998 and 1999. These

data are presented in the sectional report which is part of the Tetra Pak Life Cycle Assessment (LCA) of Packaging Material for the Brazilian market (Garcia 2000).

The data concerning the manufacturing of aluminum foil were based on data collected between 1998 and 2000 and relative to average aluminum foil, the life cycle inventory of which integrated in the Project 'Life Cycle Assessment of Aluminum Products' (Gatti 2000).

2.8 Brazilian municipal solid waste management

The inventories presented in this paper also include the distribution of the packaged product and their final disposal. Furthermore, the final destination of the residues, and the recycling process practices in the country have been taken into account.

According to the Brazilian Institute of Statistics and Geography – IBGE (2000) 228,413 tons of garbage are collected daily in Brazil, an amount equivalent to 79.9% of all the garbage produced in the country. To modelate the final disposal of packaging materials, the Average Brazilian Municipal Solid Waste Management as surveyed through the census of 2000 was taken into consideration: 79.9% of all garbage is collected and 20.1% is not collected. Of all collected garbage, 21.3% ends up in open dumps, 37.0% goes to controlled landfills, 36.2% is processed in sanitary landfills and 5.5% have other destinations (incineration, etc.). Aerobic degradation was assumed for the degradation of cellulose materials that ends up in open dumps, have other destinations or are not collected. Anaerobic degradation of cellulose with generation of the same molar fraction of CO_2 and methane was assumed for the garbage that ends up in sanitary or controlled landfills. Neither polyethylene nor aluminum has been considered to contribute with any gas emission.

3 Results

3.1 Energy consumption

Energy requirement is one of the major parameters of the life cycle inventories, since it gives us an idea of the relative importance of each of the steps, all of which consume energy either directly or indirectly. Comparison of the total energy consumption involved in the whole life cycle of the two analyzed situations for the long-life milk package material system investigated in this study shows that the total reduction of the energy requirement of the system resulting from the increase of the recycling rate (2% to 22%) is 154 MJ/1,000 L milk or about 6%:

– 2% recycling: Total energy consumption: 2,505 MJ/ 1,000 L milk. (2,309 MJ for packaging system, 30 MJ for filling, 164 MJ for distribution transport and 3MJ for final disposal
– 22% recycling: Total energy consumption: 2,351 MJ/ 1,000 L milk. (2,156 MJ for packaging system, 30 MJ for filling, 164 MJ for distribution transport and 2MJ for final disposal

The 20% increase in the recycling is exclusively relative to the recycling of higher amounts of the cardboard contained in the Tetra Pak aseptic package (75%), which represents about 47% of the packaging material system. Thus, the increase of cardboard recycling represents 7% of the total packaging mass. Considering that the item 'packaging system' represents 92% of the energy consumption of the evaluated system, a maximum energy reduction of 6.7% is expected theoretically. The energy involved in the transport of post-consumption packages to recycling plants is incorporated into the item 'Packaging system'.

Lundholm and Sundström (1985) have found a similar level of energy consumption of 2430 MJ/1000 liters of juice using a dozen 1 liter cartons (Tetra Pak aseptic) wrapped in a corrugated paperboard tray and landfill disposal of post consumption residues.

3.2 Natural resources consumption

In addition to the general reduction of the energy requirement, the increase in the recycling rate from 2% to 22%, also brought about a reduction in the consumption of important natural resources (**Fig. 2**) 8% (130 kg) reduction in the consumption of water; 7% reduction in the consumption of coal; 11% (18 kg) reduction in the consumption of wood; 10% (12 m²/year) reduction in land use (reforesting area) and 7 % reduction in landfill volume.

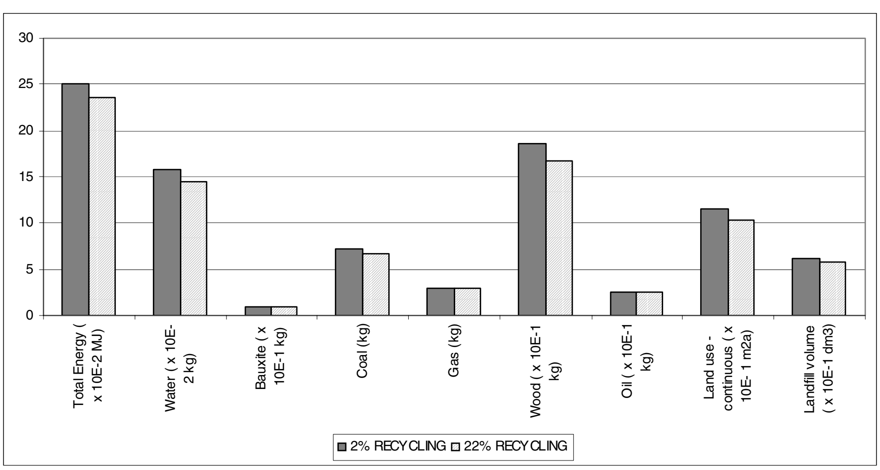

Fig. 2: Comparison of energy involved and consumption of natural resources associated with the system, considering recycling rates of 2% and 22% of the Tetra Pak Aseptic package

In the specific case of Brazil, the reduction of the amounts of water used for industrial purposes is a crucial issue since the country lacks the capacity to treat sewage and waste waters adequately. Since the cellulose industry requires very high amounts of water, the increase of the recycling rate saved 129 liters of water per functional unit of 1,000 liters of milk.

Coal and part of the wood are used mainly as fuel in factories producing cellulose from wood subsequently to be transformed into paper, cardboard, corrugated paperboard, etc. The wood in this inventory is made up basically of pine and eucalyptus and stands as the most preserved resource as a result of increasing the recycling rate from 2% to 22%.

Associated with the reduction in the use of wood is the reduction in continuous land use. The increase of the recycling rate releases 12 m^2.year of reforesting area, allowing, for example, this area to be used for other purposes, or making this area simply available for leisure.

Another significant benefit is the reduction of the volume required for final disposal (as a result of the reduction of both the process waste and the amount of material that is recycled), that is landfill and/or open dump volume space. The reduction of the final landfill volume due to the increase of the recycling rate from 2% to 22% was 7.5%, considering the apparent density of each residue.

The increasing need to create new sites for the final disposal of garbage is an important issue since, in addition to being costly, it increases the risks of contamination of deep-seated water and causes a bad smell in the imediate vicinities of these sites.

The increase in the consumption of natural gas (0.3%) and oil (0.5%) are much smaller than the benefits coming from the reduction in the consumption of water, wood, coal and land use, between 7 and 11%.

3.3 Air pollutants

With the increase of the recycling rate from 2 to 22%, a reduction in all the most significant emissions into the atmosphere may be noticed, as shown in **Fig. 3**: a reduction of 18% (640 g) in the emission of methane; 0.1% (99 g) in the emission of non-renewable CO_2, a reduction of 5% (17 g) in the emission of VOC (not alkanes, alkenes, alkynes, aldehydes, aromatic and halogenated); a reduction of 8% (108 g) in CO emission; a reduction of 6% (88 g) in the emission of sulphur oxides (SO_x); a reduction of 8% (108 g) in the emission of nitrogen oxides (NO_x) and a reduction of 10% (69 g) in the emission of particulates.

The greatest reductions are relative to greenhouse gases, such as CH_4, non-renewable CO_2 and CO. The reduction on the level of particulates is mainly due to the substitution of virgin by recycled pulp.

3.4 Water pollutants

The benefits relative to emissions into water bodies were a little smaller than those determined concerning emissions into the atmosphere, as shown in **Fig. 4**. The following, most significant reductions of emissions into bodies of water were observed: a reduction of 9% (7 g) in BOD; a reduction of 10% (40 g) in COD and a reduction of 6% (5 g) in Total Suspended Solids.

If, on the one hand, only benefits resulted from the increase of the recycling rate from 2 to 22% in terms of the energy requirement consumption of natural resources and emissions into the atmosphere and water bodies, it is also true that a significant increase of 57% (14 g) was observed in the emission of Total Dissolved Solids –(TDS) as compared to the recycling rate of 2%.

3.5 Contribution analysis

Contribution Analysis of the final inventory parameters' values of the steps of the packaging system, filling, transport and final disposal, shows that most of the emissions into the atmosphere and into water bodies are directly associated with the packaging system, followed by the emissions inherent to the shipping of the raw materials used to manufacture the packaging (Tetra Pak aseptic package, corrugated paperboard tray, shrink film and pallet), transport of the packaging material to the dairy plant and distribution of the packaged product. Contribution Analysis of the two recycling rates (2 and 22%) generates practically the same inventory numbers.

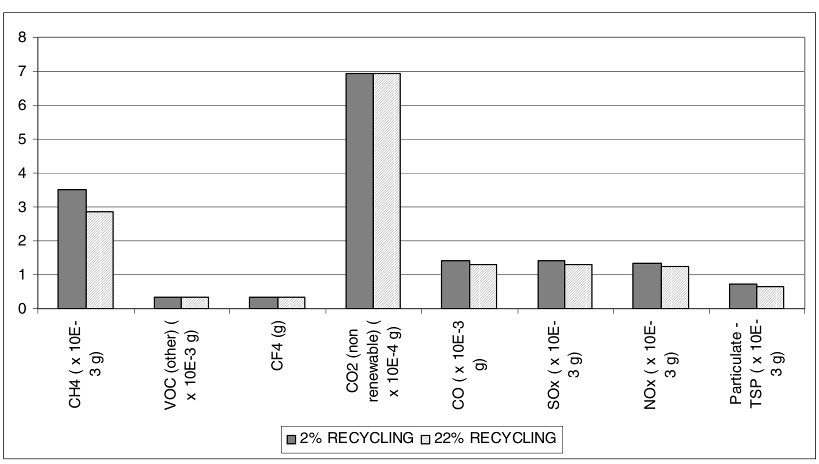

Fig. 3: Comparison of the main air emissions associated with the system, considering recycling rates of 2% and 22% of the Tetra Pak Aseptic package

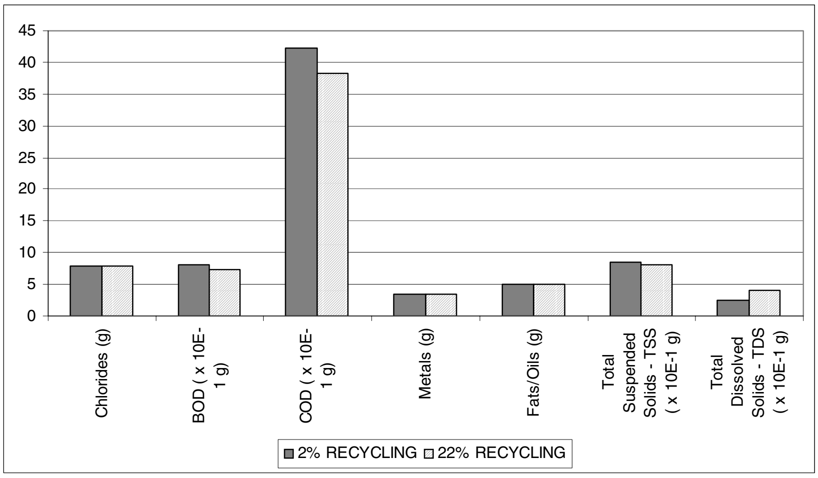

Fig. 4: Comparison of the main emissions into water bodies associated with the system, considering recycling rates of 2% and 22% of the Tetra Pak Aseptic package

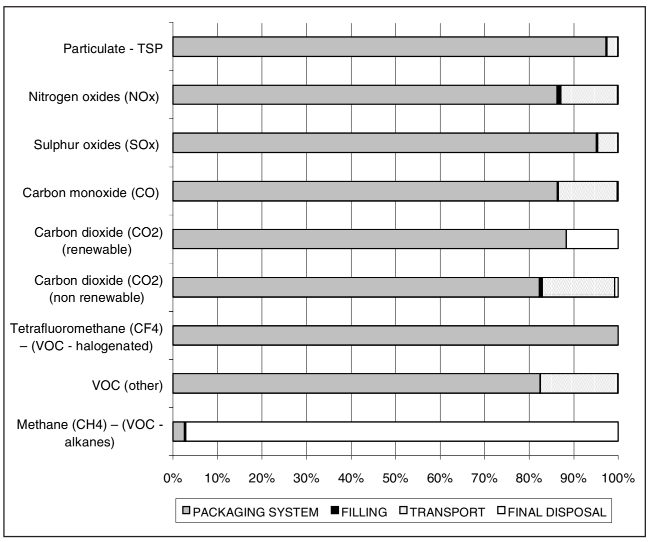

Fig. 5: Contribution Analysis of the different steps in relation to the main inventoried air emissions, considering the system with a recycling rate of 22%

The greatest difference in contribution by each of the individual steps is found in air emissions as can be seen in **Fig. 5**. The packaging system is responsible for more than 80% of almost all significant emissions into the atmosphere, except methane. Methane is emitted mainly at the final disposal of the packaging materials (98 and 97%, for the 2 and 22% recycling rate scenarios, respectively) and stem from the anaerobic decomposition of the cardboard occurring in landfills. For the same reason, the final disposal stage is also responsible for approximately 12% of the emission of renewable carbon dioxide.

4 Discussion

The reduction in the energy requirement is of the same order of magnitude as the increase of recycled cardboard mass, showing that any alterations in the process or recycling rate are related and limited to this proportionality among the different materials that make up the packaging system.

After analyzing the type of energy involved in two recycling rates cases:

- 2% recycling: Total energy consumption: 2,505 MJ/1,000 L milk. (366 MJ of hydroelectric, 1,208 MJ of biomass, 931 MJ of fossil),
- 22% recycling: Total energy consumption: 2,351 MJ/1,000 L milk. (361 MJ of hydroelectric, 1,059 MJ of biomass, 931 MJ of fossil)

It can be concluded that the most important difference comes from the energy saved by the reduction of biomass – 149 MJ. Thus, the significant distance to recycling plants – 900 km on average, have a smaller impact on total energy consumption than energy savings that result from the substitution of virgin by recycled materials.

The reduction of the emissions into the atmosphere due to the increase of the recycling rate from 2 to 22% brought about a reduction of 15.4 kg CO_2 equiv or 9.7% in GWP. In this evaluation, the values adopted for the GWP are for a 100-year horizon (IPCC 2005).

The reductions in COD, BOD and TSS emissions benefit the Southern region of the country more specifically, which has a lower population density than the Southeastern region where many of the recycling plants are located. Therefore, in order to obtain a tangible environmental advantage for recycling it is necessary to improve the wastewater treatment step of the recycling processes.TDS is a measure of the combined content of all inorganic and organic substances contained in a liquid which are present in a suspended form, with size smaller than two micrometers. The high value results from the greater emission of dissolved solids during paper recycling, since this process increases the quantity of substances dissolved in wastewater, a feature also common to recycling processes of other materials. The environmental performance of a single manufacturer of virgin cardboard is compared to the average environmental performance of waste paper processors. This single step of recycling processes may account for the significant difference found and is clearly a key issue for the improvement of the overall performance of recycling plants. In fact, people are not concerned with this parameter and the main purpose of efluent

treatments is to reduce COD and DBO, by increasing or improving the aeration steps to stimulate digestion of the organic content of wastewater.

The inputs used in the manufacture of the packaging materials such as caustic soda, sodium sulphate, aluminum sulphate, kaolin, starch, inks represent from 0.05% up to 5% of the total mass of the paper produced, therefore their exclusion of the boundaries of this study would not modify the results to any significant extent. On the other hand, the exclusion of stages such as the life cycle of milk at farms, dairies and the consumer phase do significantly affect the findings. These steps have potential environmental impacts such as eutrophication and GWP and should be included in future studies.

5 Conclusions

Comparison of the total energy consumption involved in the whole life cycle of the two analyzed situations for the long-life milk package material system investigated in this study shows that the total reduction of the energy requirement of the system resulting from increasing the recycling rate is about 6%.

In addition to the general reduction of the energy requirement, the increase in the recycling rate from 2% to 22%, also brought about a reduction in the consumption of important natural resources such as water (8%) wood (11%), and reforesting area (10%).

The most significant reductions of air pollutants were: methane (18%), VOC (5%), CO (8%), SO_x (6%), NO_x (8%) and particulates (10%). Since many of these are greenhouse gases, a reduction of 15.4 kg CO_2 equiv or 9.7% in GWP was calculated.

The most significant reductions of emission into water bodies observed were: COD (10%), BOD (9%) and Total Suspended Solids – TSS (6%). A unique drawback directly caused by the increase of the recycling rate was an increase of 14.4 g Total Dissolved Solids - TDS emission (57%). In other words, although the overall balance of water emissions is positive the improvement of wastewater treatment processes in paper recycling plants is a key issue. It may be concluded that the increase of the recycling rate brings about a series of benefits in terms of reduction of energy and natural resource consumption, GWP reductions, air pollutant and of most water emissions. In this case, the increase of the recycling rate improved the overall environmental performance of the aseptic Tetra Pak system for milk.

Acknowledgments. The authors are grateful to TETRA PAK LTDA and FAPESP – The State of São Paulo Research Foundation for the financial support.

References

Associação Brasileira do Alumínio – ABAL (2003): Guia Técnico do Alumínio. Compatibilidade do alumínio e suas ligas com alimentos e produtos químicos, 7. ABAL, São Paulo, 128 pp

Andrady A (1990): Weathering of Polyethylene (LDPE) and Enhanced Photodegradable Polyethylene in the Marine. J Appl Polym Sci 39, 363–370

Bloemhof J, Nunen JV, Vroom J, Linden AV, Kraal A (2001): One and Two Packaging in the Dairy Sector. ERIM Report Series Research in Management. 13 pp. Electronic address: <ideas.repec.org/p/dgr/eureri/2001118.html>, accessed in Feb 2006

Bousted I (1992): Eco-balance methodology for commodity thermoplastics. The European Centre for Plastics in the Environment. PWMI, Brussels, 25 pp

Clarke W (2000): Degradability of Liquid Paper Board in Landfills (A.C.N. 055 584 819). CRC for Waste Management and Pollution Control Limited, Sydney, 9 pp

Coltro L, Castilho G, Garcia EEC (2003): Life Cycle Inventory for Electric Energy System in Brazil. Int J LCA 8, 290–296

Environment Agency (Draft, November 2002): Guidance on the management of landfill gas. Electronic address: <www.environment-agency.gov.uk>, accessed in March 2005

Environmental Protection Agency (May 2002): Landfilling. In: Solid Waste Management and Greenhouse Gases – A Life-Cycle Assessment of Emissions and Sinks, 2nd Ed. EPA530-R-02-006. Electronic address: <www.epa.gov/epaoswer/non-hw/muncpl/ghg/greengas.pdf>, accessed in March 2005

Faiz A, Weaver CS, Walsh MP (1996): Air pollution from motor vehicles: standards and technologies for controlling emissions. The World Bank, Washington, 249 pp

Finnveden G, Ekvall T (1998): Life-cycle assessment as a decision-support tool – The case of recycling versus incineration of paper. Resour Conserv Recycl 24, 235–256

Garcia EEC et al. (2000): Análise de Ciclo de Vida de Embalagens para o Mercado Brasileiro, Relatório Setorial Tetra Pak Ltda (available in Portuguese, confidential document for restricted use), 139 pp

Gatti JB et al. (2000): Life Cycle Assessment of Aluminum Products, CETEA Report P004/00, (confidential document for restricted use), 88 pp

Hadad D, Geresh S, Sivan A (2005): Biodegradation of polyethylene by the thermophilic bacterium *Brevibacillus borstelensis*. J Appl Microbiol 98 (5) 1093–1110

Hischier R, Althaus H-J, Werner F (2005): Developments in wood and packaging materials life cycle inventories in ecoinvent. Int J LCA 10 (1) 50–58

Hospido A, Moreira MT, Feijoo G (2003): Simplified life cycle assessment of Galician milk production. Int Dairy Journal 13, 783–796

Hunt RG (1995): LCA considerations of solid waste management alternatives for paper and plastics. Resour Conserv Recycl 14, 225–231

Instituto de Pesquisas Tecnológicas / Compromisso Empresarial Para Reciclagem (2000): Lixo municipal. Manual de Gerenciamento Integrado. IPT/CEMPRE, São Paulo, 370 pp

Intergovernmental Panel on Climate Change – IPCC (2001): Third Assessment Report – Climate Change 2001: The Scientific Basis. Radioactive Forcing of Climate Change. Global Warming Potentials. Chapter 6. Electronic address: <www.grida.no/climate/ipcc_tar/wg1/247.htm>, accessed in March 2005

International Organization for Standardization – ISO 14040 (1997): Environment Management – Life Cycle Assessment – Principles and Framework. Geneva

International Organization for Standardization – ISO 14041(1998): Environment Management – Life Cycle Assessment – Goal and scope definition and inventory analysis. Geneva

Lundholm MP, Sundström G (1985): Resource and environmental impact of tetra Brik aseptic carton and of refillable and non-refillable glass bottles. Malmö, 174 pp

Mourad A et al. (2000a): Análise de Ciclo de Vida de Embalagens para o Mercado Brasileiro, Relatório Setorial BRACELPA – Associação Brasileira de Celulose e Papel (available in Portuguese language, confidential document for internal use), 137 pp

Mourad A et al. (2000b): Análise de Ciclo de Vida de Embalagens para o Mercado Brasileiro, Relatório Setorial ABPO – Associação Brasileira de Papelão Ondulado (available in Portuguese language, confidential document for internal use), 120 pp

Rodriguez C, Hiligsmann S, Ongena M, Charlier R, Thonart P (2005): Development of an enzymatic assay for the determination of cellulose bioavailability in municipal solid waste. Biodegradation 16, 415–422

Serviço Nacional De Aprendizagem Industrial / Instituto De Pesquisas Tecnológicas (1998): Celulose e Papel. Tecnologia de Fabricação da Pasta Celulósica, 2. SENAI/IPT, São Paulo, 559 pp

Tuomela M, Vikman M, Hatakka A, Itävaara M (2000): Biodegradation of lignin in a compost environment: A review. Bioresour Technol 72, 169–183

Wilde B. D, Boelens J (19980: Prerequisites for biodegradable plastic materials for acceptance in real life composting plants and technical aspects. Polym Degrad Stabil 59, 7–12

Received: July 6th, 2006
Accepted: June 9th, 2007
OnlineFirst: June 10th, 2007